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Influence of Mandibular Fixed Retainers on Diagnostic Quality of Cranial MRI

by

Norman E. Carter

A Thesis submitted in partial satisfaction of
the requirements for the degree of
Master of Science in Orthodontics and Dentofacial Orthopedics

March 2008

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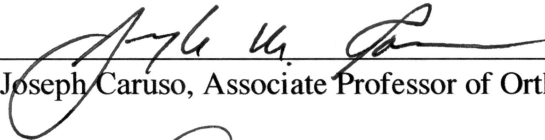
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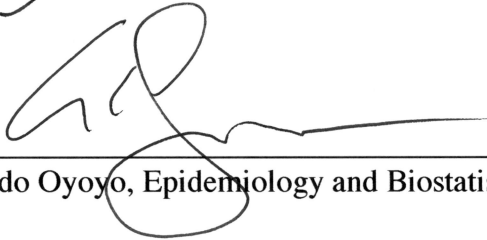


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Udo Oyoyo, Epidemiology and Biostatistics

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ABBREVIATIONS

DWI	Diffusion Weighted Images
GRE	Gradient Echo
MR	Magnetic Resonance
MRI	Magnetic Resonance Imaging
T	Tesla
TMA	Titanium Molybdenum Alloy
T1	T1 Sagittal
T2	T2 Axial
ROC	Receiver Operating Characteristic

ABSTRACT

Influence of Mandibular Fixed Retainers on Diagnostic Quality of Cranial MRI

by

Norman E. Carter

Master of Science, Graduate Program in Orthodontics and Dentofacial Orthopedics
Loma Linda University, March 2008
Dr. V. Leroy Leggitt, Chairperson

The purpose of this study was to evaluate the diagnostic quality of MR images taken on subjects with different types of orthodontic lingual retainers in place. The study provides guidelines and recommendations for use of lingual retainer materials in those patients who are or may potentially undergo routine magnetic resonance imaging. Ten subjects had impressions taken and models made for retainer tray fabrication. Removable trays with each lingual retainer material incorporated in them were fabricated from the models. Subjects underwent scans with each of the five test trays in place. T1 sagittal (T1), T2 axial (T2), gradient echo (GRE), and diffusion weighted imaging (DWI) were evaluated independently by three neuroradiologists for degree of distortion and diagnostic ability. The Friedman test, a repeated measures one-way ANOVA correlation, established statistically significant differences ($p < .05$) in distortion ranking of images due to lingual retainer material. Post-hoc comparison using a paired Wilcoxon signed rank test determined statistically significant differences to be between stainless steel and all other materials for T1, T2, and GRE imaging modalities. An intraclass correlation coefficient of .706 showed good agreement between readers with associated 95% confidence intervals. The results of this study show that stainless steel mandibular retainers caused statistically significant distortion in MR images at the base of the tongue, body of the

mandible and hard palate in the T1, T2 and GRE imaging modalities. The distortion scores indicate images are nondiagnostic. RibbondTM, gold, and TMA did not cause a statistically significant amount of distortion of any of the images.

CHAPTER ONE

INTRODUCTION

“Magnetic resonance imaging has become one of the most powerful diagnostic tools in radiology and diagnostic sciences.”¹² As of 2004, more than 150 million MRI procedures had been performed.¹³ Benefits of MRI include high tissue contrast and accuracy, imaging versatility (with various planes of section readily available), low energy radiation (that appears to be safe under normal operating conditions) and MRI is a technique that is noninvasive and nonionizing.¹¹

Unfortunately, the diagnostic quality of MR scans taken in the head and neck region may be inhibited due to artifacts caused by metallic materials in the scan area.¹⁷ The tendency of a material to attract magnetic lines of force is the materials magnetic susceptibility.¹¹ Magnetic susceptibility artifacts associated with metallic materials are dependent on the type, size, shape and orientation of the metal object.¹⁴ Common metallic materials that cause cranial MR image artifacts include dental or orthopedic implants, dental cast restorations, aneurysm clips and stainless steel orthodontic appliances.^{1,18}

The selection of orthodontic retention methods is a controversial topic with no agreement being reached in the literature. The adequate length of retention time to prevent relapse has not been confidently established. Recent studies have reached the consensus that relapse is not predictable and that if orthodontic results are to be maintained long-term, indefinite retention is required.^{2,3,5} Bearn⁴ concluded that “bonded

fixed retainers are now in common use for long-term esthetic retention”. Long-term retention is necessary to prevent relapse because maintaining completely stable results after orthodontic treatment (without retention) is not realistic.⁵

The bonded fixed retainer consists of an orthodontic wire attached to the lingual surface of teeth with composite bonded to an acid-etched enamel surface. Literature shows many variations of techniques for fixed retention including different wire diameter, wire type and even the use of resin fiberglass strips.⁶⁻⁸ With no agreed upon system of retention in the literature, the choice is left up to the clinical orthodontist in consult with the patient as to the method of retention.⁹

While some orthodontic fixed retainers are made of non-metallic materials, most contemporary bonded fixed lingual retainers are composed of some type of metallic wire. Klocke¹⁵ reviewed the literature and found that “Information on orthodontic wires within MRI magnetic fields is very limited thus far”. A standardized assessment of rotational and translational forces (within a MR field) was done with chromium alloy orthodontic wire. The study concluded that while marked forces were present, orthodontic wires would not dislocate from orthodontic appliances if the wires were attached at multiple spots.²⁰ Studies by Okano et al,¹⁷ and Sadowsky et al,¹⁹ conducted with 0.5 Tesla MR machines to assess the temporomandibular joint concluded that orthodontic archwires should be removed prior to imaging. Recently it was shown that orthodontic wires made of steel alloys come under rotational and translational forces in the magnetic field that are much greater than gravitational forces.¹⁵ Wires made of cobalt-chromium, titanium-molybdenum and nickel-titanium alloys had no or minor interactions with magnetic fields

in the study.¹⁵ Orthodontic springs and auxiliary appliances are also subject to significant rotational and translational forces.¹⁶

There are few studies which address the artifacts caused by metals in the oral and maxillofacial region in clinically relevant situations. Artifacts caused by common metallic objects in this region “could hinder the capability of accurately identifying an anatomic region and potential pathosis.”¹¹ The purpose of this study was to evaluate the diagnostic quality of MR images taken on subjects with different orthodontic lingual retainers in place simulating a clinically relevant situation. This study provides guidelines and recommendations for use of lingual retainer materials in those patients who are or may potentially undergo routine magnetic resonance imaging.

CHAPTER TWO

MATERIALS AND METHODS

Patient Selection

Ten subjects meeting the following criteria were selected for the study: 1) no medically related metallic implanted devices (no aneurysm clips, pace makers, etc.), 2) no metal containing dental restorations (no metallic fillings, dental implants, metal crowns, porcelain fused to metal, etc.), 3) over 18 years of age, 4) male or female (females not pregnant) and 5) subjects were able to receive the scans without sedation. Subjects were given an informed consent explaining the full purpose of the study including risks and benefits before the imaging procedures. Seven of the subjects were male and three were female with ages ranging from 21 years to 37 years of age. IRB approval was obtained before the MR scans were conducted.

Retainer Tray Construction

Retainer trays for this study were fabricated to be removable while simulating the intraoral position of a fixed orthodontic lingual retainer. In addition to a control appliance with no retainer material incorporated, the appliances contained one of the following retainer materials: 1) Ribbond[®] orthodontic retainer (polyethylene fiber), 2) Ortho FlexTech[™] (14 karat gold chain, Reliance[®]), 3) Beta III titanium (TMA) (Bendaloy[™] RMO[®]) and 4) a prefabricated bondable stainless steel lingual retainer with cuspid metallic pads (Ormco[®]). The length of each retainer material was cut to match the

length of the prefabricated stainless steel retainer. The appliance trays were fabricated using the following procedure. Polyvinylsiloxane (Aquasil Monophase, Dentsply Caulk, Milford, DE) impressions of the mandibular arch of each subject were taken and five plaster models (Heraeus Kulzer, South Bend, IN) for each patient were made from the impressions. After trimming and cleaning the models of any debris Al-Cote[®] separating agent (Dentsply Trubyte, York, PA) was applied to four of the five models. Once the Al-Cote[®] dried on the models the fixed lingual retainers were fashioned to follow the contours of the mandibular lingual anteriors from canine to canine at the junction of the incisal and middle one third of the clinical crown. Each retainer was held in place on the model with hot melt adhesive. Figure 1a shows an example of a mandibular arch with stainless steel wire adhered to the plaster model.

After placement of the fixed lingual retainers on the plaster models, an Essix[™] retainer tray (GAC International Inc., Bohemia, NY) was fabricated to encompass the lingual appliance and teeth using a Biostar[™] (Iserlohn, Germany) machine. The material was heated at 373° Fahrenheit for 60 seconds before being placed and pressure formed on top of the model for approximately ten seconds incorporating the orthodontic appliances directly into the Essix[™] trays. Upon removal from the models, the trays were trimmed with scissors and placed in an ultrasonic water bath to remove any residual plaster. Each Essix[™] tray was trimmed, smoothed and tried in the respective subjects' mouth to ensure fit and comfort. Figure 1b shows a stainless steel lingual retainer embedded in an Essix[™] retainer tray.

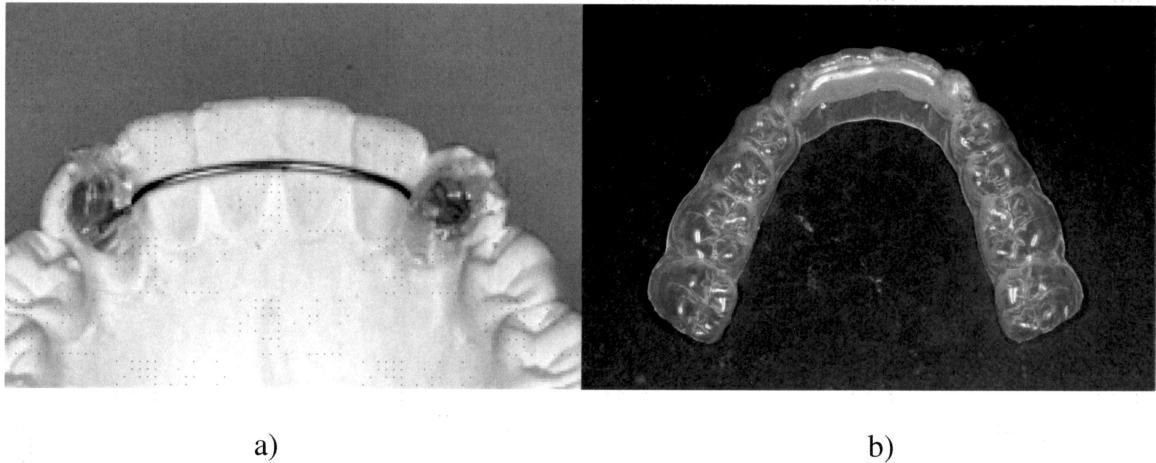


Figure 1. a) Stainless steel lingual retainer attached to plaster model with hot melt adhesive, b) Essix[™] stainless steel retainer tray.

MRI Imaging and Data Collection

All MR imaging was done at Loma Linda University on a 1.5 T MR imaging system (Siemens Medical Solutions, Sonata, Erlangen, Germany) using a standard quadrature head coil. Imaging sequences included axial fast spin echo T2 weighted images (TR/TE=4000/89 msec), axial and sagittal conventional spin echo T1 weighted images (TR/TE=481/11 msec, 5 mm thick, 20% gap) and axial gradient recalled echo images (TR/TE=679/26 msec, flip angle 25 degrees, 4 mm thick). A diffusion weighted sequence (TR/TE=6300/137 msec, 5 mm thick) was also performed.

Each subject entered the scanner with the initial trial tray in place. Following the initial set of imaging sequences, subsequent trays were placed and the imaging sequence was repeated. MR scans were randomly assigned an identification code to ensure rating of the scans was done in a blind manner.

Evaluating Images for Distortion/Artifact

Three board certified neuroradiologists from Loma Linda University Medical Center evaluated the images using the DICOM image viewer eFilm Lite™ version 2.1.0. Nine regions of the head were assessed: 1) base of the tongue, 2) body of the mandible, 3) hard palate, 4) orbits/globes, 5) nasopharynx, 6) pituitary gland, 7) frontal lobe, 8) temporal lobes and 9) brainstem. The neuroradiologists were asked to rank the images according to distortion of these regions using a modified ROC (receiver operating characteristic) method of distortion classification (Table 1).

T1 sagittal, T2 axial, gradient echo (GRE), and diffusion weighted images (DWI) were evaluated. When viewing the diffusion weighted scan, only the frontal lobe, temporal lobes, and brainstem were examined. No scores were given to any anatomic region the raters felt was not included in the scan. To confirm interrater and intrarater reliability, each rater reevaluated three subjects based on the results of a computer generated random assignment.

Table 1. Modified ROC method of distortion classification.

Score	Image appearance	Diagnostic/Nondiagnostic
1	No distortion/artifact	Diagnostic
2	Minimal distortion/artifact	Diagnostic
3	Moderate distortion/artifact	Moderately diagnostic
4	Severe distortion	Nondiagnostic
5	Complete obliteration	Nondiagnostic

Statistical Analysis

Statistical analysis was performed using SPSS 12.0 for Windows (SPSS, Chicago, Ill). Differences between materials, anatomic sites, and imaging sequences were analyzed for statistical significance by means of the Friedman test, a one way repeated measures ANOVA correlation. Post-hoc comparison was performed using a paired Wilcoxon signed rank test to determine statistically significant differences. A p-value of less than .05 indicated a statistically significant difference.

Interrater agreement between reviewers was assessed for each material, anatomical site, and imaging sequence using the intraclass correlation coefficient with a 95% confidence interval.

CHAPTER THREE

RESULTS

An intraclass correlation coefficient (ICC) was used to establish reliability of the raters. The ICC values showed good agreement at .706 between the three readers at a 95% confidence interval as seen in Table 2.

Table 2. Intraclass Correlation Coefficient.

	Intraclass Correlation	95% Confidence Interval	
		Lower Bound	Upper Bound
Single Measures	.706	.570	.787

Two-way random effects model where both people effects and measures effects are random

The Friedman test for lingual retainer material effect reported a statistically significant difference in distortion ($p < .05$) among specific anatomical regions due to the type of lingual retainer material present in each imaging modality (Tables 3-5). The T1 sagittal, T2 axial, and gradient echo imaging modalities had statistically significant p -values in the anatomical regions of the base of tongue, body of mandible, and hard palate (Tables 3-5). In addition, the orbits/globes anatomical region showed a statistical difference within the T1 sagittal imaging modality ($p = .015$). Lingual retainer material appeared to have no statistically significant effect on the diffusion weighted imaging

modality (DWI) for the three anatomical regions (frontal lobe, temporal lobes, and brainstem) that were viewed (Table 6).

Further analysis using the Wilcoxon signed rank test was applied to determine between which lingual retainer materials these statistically significant differences occurred within each imaging modality. When comparing lingual retainer materials within the T1 sagittal imaging modality at the base of the tongue statistically significant difference were seen between stainless steel and the control ($p = .023$), Ribbond and stainless steel ($p = .014$), and gold and stainless steel ($p = .008$) respectively. A comparison between stainless steel and TMA was not considered statistically significant ($p = .058$). Stainless steel was significantly different then all other materials for the anatomical regions of the body of the mandible and the hard palate as shown in bold (Table 7). For the T1 sagittal imaging modality only, at the region of the orbits/globes, significant differences were found between stainless steel and control, gold, and TMA.

Comparing the materials in the T2 axial imaging modality found significant differences between stainless steel and all the other materials for the base of the tongue, body of mandible, and hard palate. The control-stainless steel comparison gave p-values of (.046, .004, and .004 respectively) for these anatomic regions. Similar p-values were obtained when comparing stainless steel to the remaining materials, Ribbond, gold, and TMA (Table 8).

Statistically significant differences similar to those of the T2 imaging modality were also seen for comparison of materials in the GRE imaging modality. However, no statistically significant difference was found when comparing TMA to stainless steel at the base of the tongue (Table 9).

The mean ranks in Tables 3-6 are depicted on line graphs in Figures 2-5. The graphs for the T1, T2, and GRE imaging modalities show stainless steel consistently ranked highest in terms of distortion at the base of tongue, body of mandible, and hard palate (Figs. 2-4). Mean distortion rankings of the materials for the DWI imaging modality were similar for the cranial anatomic regions (frontal lobe, temporal lobes, brainstem) (Table 6 and Fig. 5).

The Freidman test revealed no significant differences between materials within the diffusion weighted imaging modality. All of the p-values were greater than 0.1 (Table 6). This result was confirmed by the Wilcoxon signed rank test when paired comparisons of the materials were made.

Table 3. Friedman test comparing lingual retainer material effect: mean rank for materials at anatomic regions within T1 imaging modality.

	Control	Ribbond	Gold	TMA	Stainless Steel	P-value
base of tongue	2.80	2.55	2.30	3.05	4.30	0.001
body of mandible	2.70	2.10	2.70	2.50	5.00	0.0001
hard palate	2.50	2.30	2.50	2.70	5.00	0.0001
orbits/globes	2.80	3.05	2.80	2.55	3.80	0.015
nasopharynx	2.75	3.00	2.75	3.00	3.50	0.155
pituitary gland	3.00	3.00	3.00	3.00	3.00	1.000
frontal lobe	3.00	3.00	3.00	3.00	3.00	1.000
temporal lobes	2.90	2.90	3.15	3.15	2.90	0.406
brainstem	2.85	2.85	3.10	3.35	2.85	0.171

Table 4. Friedman test comparing lingual retainer material effect: mean rank for materials at anatomic regions within T2 imaging modality.

	Control	Ribbond	Gold	TMA	Stainless Steel	P-value
base of tongue	3.05	2.35	2.80	2.75	4.05	0.003
body of mandible	2.60	2.55	2.40	2.45	5.00	0.0001
hard palate	2.60	2.40	2.40	2.60	5.00	0.0001
orbits/globes	2.70	2.70	2.95	3.45	3.20	0.302
nasopharynx	2.95	3.10	2.95	3.00	3.00	0.998
pituitary gland	2.80	3.05	3.05	2.80	3.30	0.406
frontal lobe	3.00	3.00	3.00	3.00	3.00	1.000
temporal lobes	3.00	3.00	3.00	3.00	3.00	1.000
brainstem	3.00	3.00	3.00	3.00	3.00	1.000

Table 5. Friedman test comparing lingual retainer material effect: mean rank for materials at anatomic regions within GRE imaging modality.

	Control	Ribbond	Gold	TMA	Stainless Steel	P-value
base of tongue	2.45	2.95	2.45	3.00	4.15	0.008
body of mandible	2.60	2.40	2.80	2.20	5.00	0.0001
hard palate	2.30	2.50	2.45	2.80	4.95	0.0001
orbits/globes	3.00	3.15	3.60	2.85	2.40	0.138
nasopharynx	2.75	3.00	2.95	3.20	3.10	0.903
pituitary gland	3.45	2.70	3.15	2.40	3.30	0.097
frontal lobe	2.70	3.65	3.00	2.45	3.20	0.061
temporal lobes	3.20	3.20	2.95	2.70	2.95	0.406
brainstem	3.05	3.20	2.90	2.65	3.20	0.465

Table 6. Friedman test comparing lingual retainer material effect: mean rank for materials at anatomic regions within DWI imaging modality.

	Control	Ribbond	Gold	TMA	Stainless Steel	P-value
frontal lobe	2.80	3.05	3.30	3.05	2.80	0.539
temporal lobes	3.10	3.10	2.85	2.85	3.10	0.558
brainstem	2.75	2.55	3.40	2.80	3.50	0.119

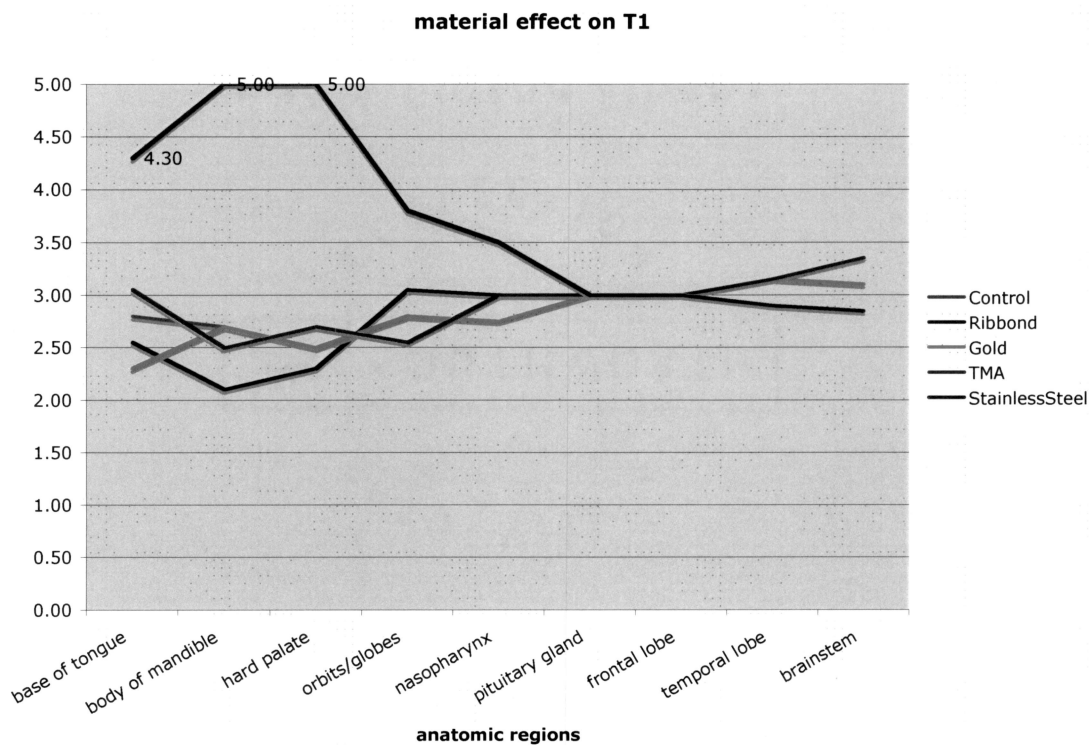


Figure 2. Line graph of material effect on T1 imaging modality.

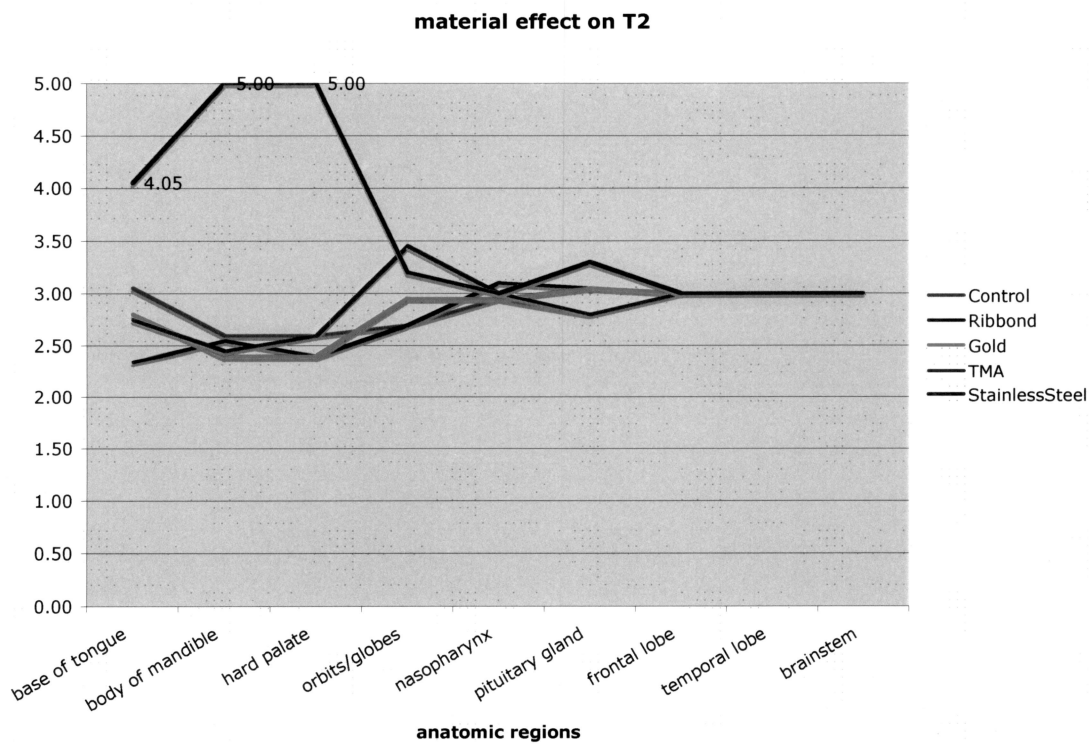


Figure 3. Line graph of material effect on T2 imaging modality.

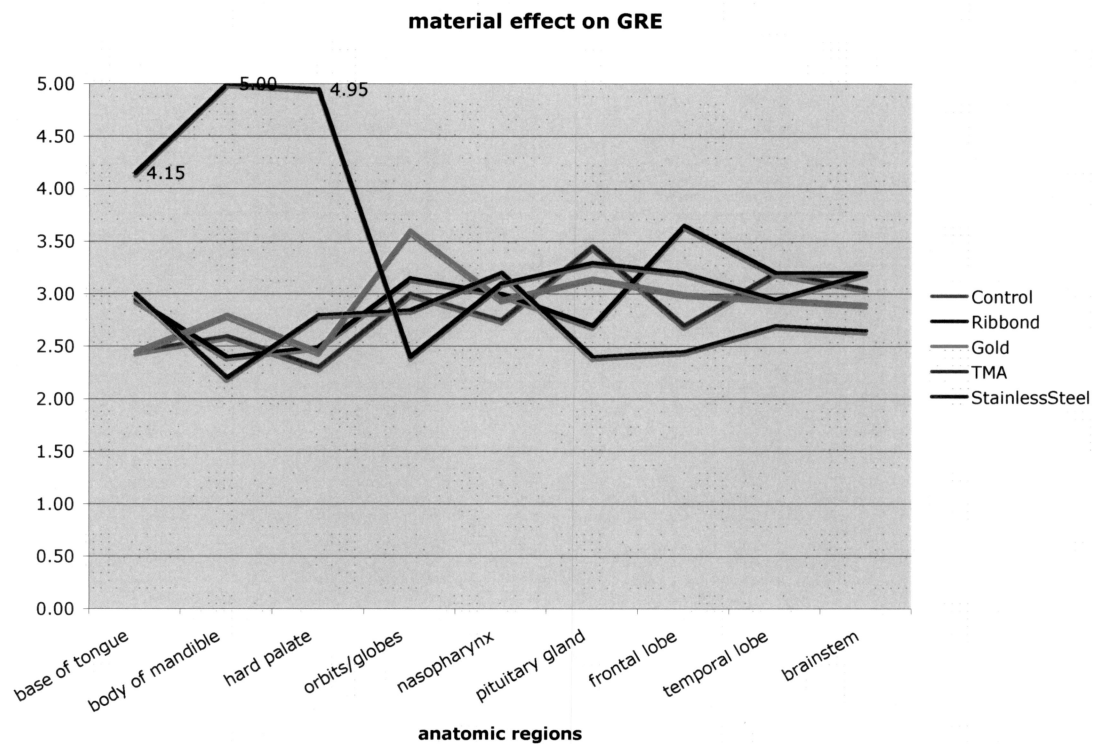


Figure 4. Line graph of material effect on GRE imaging modality.

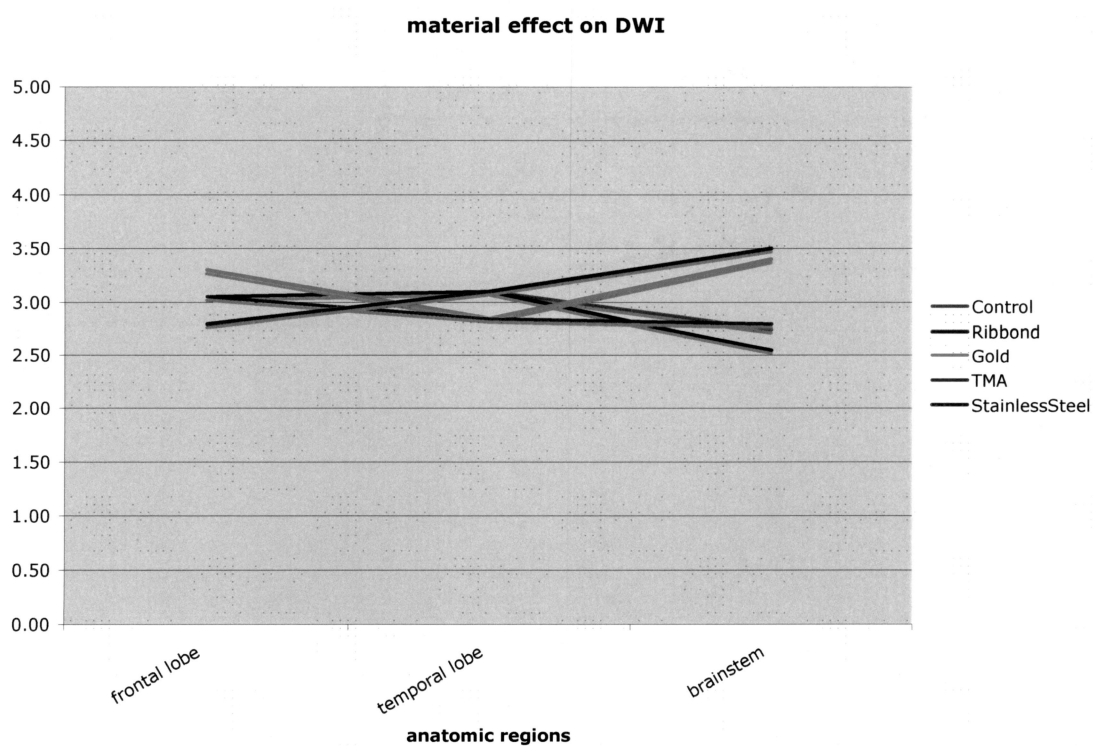


Figure 5. Line graph of material effect on DWI imaging modality.

While the Friedman test did not confirm statistically significant differences in the anatomical regions beyond those mentioned above, the Wilcoxon signed rank test did reveal statistical differences at two other regions within the GRE imaging modality. Specifically at the region of the pituitary gland ($p = .046$) when comparing stainless steel to TMA, and in the frontal lobe when comparing Ribbond to TMA ($p = .039$) [Table 9]. The Wilcoxon signed rank test found no statistically significant differences for the DWI imaging modality (Table 10).

Mean distortion scores for each imaging modality are presented in Tables 11-14 and shown in Figures 6-9. Within the T1 and T2 imaging modalities stainless steel distortion scores were above 3.0 (nondiagnostic) for the body of mandible and hard palate (Table 11 and 12 and figures 6 and 7). For all other materials and regions including stainless steel the distortion scores are below 2.0 (diagnostic). Scores for the GRE imaging modality were between 3.0-5.0 (nondiagnostic) for five of the anatomic regions (body of mandible, hard palate, orbits/globes, nasopharynx, and pituitary gland). Cranial anatomic regions (frontal lobe, temporal lobes, and brainstem) in Table 13 had mean distortion scores of 2.0-3.0. The mean distortion scores for the final imaging modality DWI ranged between 2.8 and 3.2 for all materials within the three anatomic regions imaged (Table 14).

Table 7. Wilcoxon signed rank test comparing effect of lingual retainer material on distortion at anatomical regions within T1 imaging modality.

		Base of Tongue	Body of Mandible	Hard Palate	Orbits/ Globes	Naso- pharynx	Pituitary Gland	Frontal Lobe	Temporal Lobes	Brainstem
Control-Ribbon	Z - score	-0.577	-1.649	-1.000	-1.000	-1.000	0.000	0.000	0.000	0.000
	p - value	0.564	0.083	0.317	0.317	0.317	1.000	1.000	1.000	1.000
Control-Gold	Z - score	-1.414	0.000	0.000	0.000	0.000	0.000	0.000	-1.000	-1.000
	p - value	0.157	1.000	1.000	1.000	1.000	1.000	1.000	0.317	0.317
Control-TMA	Z - score	-0.816	-1.000	-0.577	-1.000	-1.000	0.000	0.000	-1.000	-1.414
	p - value	0.414	0.317	0.564	0.317	0.317	1.000	1.000	0.317	0.157
Control-Stainless steel	Z - score	-2.271	-0.2889	-3.051	-2.000	-1.732	0.000	0.000	0.000	0.000
	p - value	0.023	0.004	0.002	0.046	0.083	1.000	1.000	1.000	1.000
Ribbon-Gold	Z - score	-1.000	-1.732	-1.000	-1.000	-1.000	0.000	0.000	-1.000	-1.000
	p - value	0.317	0.083	0.317	0.317	0.317	1.000	1.000	0.317	0.317
Ribbon-TMA	Z - score	-1.134	-1.414	-1.414	-1.342	-0.447	0.000	0.000	-1.000	-1.414
	p - value	0.257	0.157	0.157	0.180	0.655	1.000	1.000	0.317	0.157
Ribbon-Stainless steel	Z - score	-2.460	-2.919	-3.162	-1.838	-1.512	0.000	0.000	0.000	0.000
	p - value	0.014	0.004	0.002	0.066	0.131	1.000	1.000	1.000	1.000
Gold-TMA	Z - score	-1.633	-1.000	-1.000	-1.000	-1.000	0.000	0.000	0.000	-1.000
	p - value	0.102	0.317	0.317	0.317	0.317	1.000	1.000	1.000	0.317
Gold-Stainless steel	Z - score	-2.640	-2.889	-3.051	-2.000	-1.732	0.000	0.000	-1.000	-1.000
	p - value	0.008	0.004	0.002	0.046	0.083	1.000	1.000	0.317	0.317
TMA-Stainless steel	Z - score	-1.897	-2.879	-2.972	-2.236	-1.414	0.000	0.000	-1.000	-1.414
	p - value	0.058	0.004	0.003	0.025	0.157	1.000	1.000	0.317	0.157

Table 8. Wilcoxon signed rank test comparing effect of lingual retainer material on distortion at anatomical regions within T2 imaging modality.

		Base of Tongue	Body of Mandible	Hard Palate	Orbits/ Globes	Naso- pharynx	Pituitary Gland	Frontal Lobe	Temporal Lobes	Brainstem
Control-Ribbon	Z - score	-1.633	-0.378	-0.577	-0.447	-0.141	-1.000	0.000	0.000	0.000
	p - value	0.102	0.705	0.564	0.655	0.888	0.317	1.000	1.000	1.000
Control-Gold	Z - score	-1.000	-1.000	-0.577	-0.577	0.000	-1.000	0.000	0.000	0.000
	p - value	0.317	0.317	0.564	0.564	1.000	0.317	1.000	1.000	1.000
Control-TMA	Z - score	-1.000	-0.577	0.000	-1.732	0.000	0.000	0.000	0.000	0.000
	p - value	0.317	0.564	1.000	0.083	1.000	1.000	1.000	1.000	1.000
Control-Stainless steel	Z - score	-2.000	-2.889	-2.859	-1.414	0.000	-1.414	0.000	0.000	0.000
	p - value	0.046	0.004	0.004	0.157	1.000	0.157	1.000	1.000	1.000
Ribbon-Gold	Z - score	-1.342	-0.141	0.000	-1.089	-0.141	0.000	0.000	0.000	0.000
	p - value	0.180	0.888	1.000	0.276	0.888	1.000	1.000	1.000	1.000
Ribbon-TMA	Z - score	-1.089	-0.333	-0.447	-1.838	0.000	-1.000	0.000	0.000	0.000
	p - value	0.276	0.739	0.655	0.066	1.000	0.317	1.000	1.000	1.000
Ribbon-Stainless steel	Z - score	-2.530	-2.859	-2.877	-1.512	0.000	-0.577	0.000	0.000	0.000
	p - value	0.011	0.004	0.004	0.131	1.000	0.564	1.000	1.000	1.000
Gold-TMA	Z - score	0.000	0.000	-1.000	-1.414	0.000	-1.000	0.000	0.000	0.000
	p - value	1.000	1.000	0.317	0.157	1.000	0.317	1.000	1.000	1.000
Gold-Stainless steel	Z - score	-2.236	-2.879	-2.879	-0.577	0.000	-0.577	0.000	0.000	0.000
	p - value	0.025	0.004	0.004	0.564	1.000	0.564	1.000	1.000	1.000
TMA-Stainless steel	Z - score	-2.236	-2.879	-2.889	-1.000	0.000	-1.414	0.000	0.000	0.000
	p - value	0.025	0.004	0.004	0.317	1.000	0.157	1.000	1.000	1.000

Table 9. Wilcoxon signed rank test comparing effect of lingual retainer material on distortion at anatomical regions within GRE imaging modality.

		Base of Tongue	Body of Mandible	Hard Palate	Orbits/Globes	Naso-pharynx	Pituitary Gland	Frontal Lobe	Temporal Lobes	Brainstem
Control-Ribbon	Z - score	-1.414	-0.707	-1.000	-0.577	-0.577	-1.633	-1.890	0.000	-1.000
	p - value	0.157	0.480	0.317	0.564	0.564	0.102	0.059	1.000	0.317
Control-Gold	Z - score	0.000	-1.000	0.000	-1.000	0.000	-0.816	0.000	-1.000	-1.000
	p - value	1.000	0.317	1.000	0.317	1.000	0.414	1.000	0.317	0.317
Control-TMA	Z - score	-1.000	-1.300	-1.000	-0.577	-0.378	-1.890	-0.816	-1.342	-1.000
	p - value	0.317	0.194	0.317	0.564	0.705	0.059	0.414	0.180	0.317
Control-Stainless steel	Z - score	-2.530	-2.972	-2.972	-1.000	-0.577	-1.000	-1.414	-1.000	-1.000
	p - value	0.011	0.003	0.003	0.317	0.564	0.317	0.157	0.317	0.317
Ribbon-Gold	Z - score	-1.000	-1.134	-0.447	-0.378	-0.447	-0.368	-1.473	-1.000	-1.000
	p - value	0.317	0.257	0.655	0.705	0.655	0.713	0.141	0.317	0.317
Ribbon-TMA	Z - score	-0.378	-0.552	-0.577	-1.000	0.000	-1.069	-2.060	-1.342	-1.134
	p - value	0.705	0.581	0.564	0.317	1.000	0.285	0.039	0.180	0.257
Ribbon-Stainless steel	Z - score	-2.121	-2.913	-3.051	-1.732	0.000	-0.756	-1.342	-1.000	0.000
	p - value	0.034	0.004	0.002	0.083	1.000	0.450	0.180	0.317	1.000
Gold-TMA	Z - score	-1.134	-1.518	-1.414	-1.732	-0.577	-1.732	-1.414	-1.000	-0.577
	p - value	0.257	0.129	0.157	0.083	0.564	0.083	0.157	0.317	0.564
Gold-Stainless steel	Z - score	-2.530	-3.051	-3.051	-1.265	-0.447	-0.577	-0.816	-0.447	-1.000
	p - value	0.011	0.002	0.002	0.206	0.655	0.564	0.414	0.655	0.317
TMA-Stainless steel	Z - score	-1.667	-2.873	-2.887	-0.378	0.000	-2.000	-1.633	-0.816	-1.134
	p - value	0.096	0.004	0.004	0.705	1.000	0.046	0.102	0.414	0.257

Table 10. Wilcoxon signed rank test comparing effect of lingual retainer material on distortion at anatomical regions within DWI imaging modality.

		Frontal Lobe	Temporal Lobes	Brainstem
Control-Ribbon	Z - score	-0.577	0.000	-0.272
	p - value	0.564	1.000	0.785
Control-Gold	Z - score	-1.000	-1.000	-0.707
	p - value	0.317	0.317	0.480
Control-TMA	Z - score	-0.577	-1.000	0.000
	p - value	0.564	0.317	1.000
Control-Stainless steel	Z - score	0.000	0.000	-1.732
	p - value	1.000	1.000	0.083
Ribbon-Gold	Z - score	-1.000	-1.000	-1.131
	p - value	0.317	0.317	0.258
Ribbon-TMA	Z - score	0.000	-1.000	-1.000
	p - value	1.000	0.317	0.317
Ribbon-Stainless steel	Z - score	-1.000	0.000	-1.890
	p - value	0.317	1.000	0.059
Gold-TMA	Z - score	-1.000	0.000	-1.000
	p - value	0.317	1.000	0.317
Gold-Stainless steel	Z - score	-1.414	-1.000	-0.447
	p - value	0.157	0.317	0.655
TMA-Stainless steel	Z - score	-1.000	-1.000	-1.132
	p - value	0.317	0.317	0.083

Table 11. T1 mean scores of material at anatomic regions.

	Control	Ribbond	Gold	TMA	Stainless Steel
base of tongue	1.20	1.10	1.00	1.40	2.00
body of mandible	1.60	1.30	1.60	1.50	4.00
hard palate	1.10	1.00	1.10	1.20	4.00
orbits/globes	1.10	1.15	1.10	1.00	1.50
nasopharynx	1.00	1.05	1.00	1.10	1.30
pituitary gland	1.00	1.00	1.00	1.00	1.00
frontal lobe	1.00	1.00	1.00	1.00	1.00
temporal lobes	1.00	1.00	1.20	1.20	1.00
brainstem	1.00	1.00	1.20	1.40	1.00

Table12. T2 mean scores of material at anatomic regions.

	Control	Ribbond	Gold	TMA	Stainless Steel
base of tongue	1.60	1.35	1.50	1.50	2.00
body of mandible	1.60	1.55	1.50	1.50	4.00
hard palate	1.50	1.40	1.40	1.50	3.90
orbits/globes	1.20	1.15	1.30	1.50	1.40
nasopharynx	1.40	1.45	1.40	1.40	1.40
pituitary gland	1.00	1.10	1.10	1.00	1.20
frontal lobe	1.00	1.00	1.00	1.00	1.00
temporal lobes	1.00	1.00	1.00	1.00	1.00
brainstem	1.00	1.00	1.00	1.00	1.00

Table 13. GRE mean scores of material at anatomic regions.

	Control	Ribbon	Gold	TMA	Stainless Steel
base of tongue	2.90	3.10	2.90	3.20	3.70
body of mandible	3.80	3.60	3.90	3.40	5.00
hard palate	3.80	3.90	3.80	4.00	5.00
orbits/globes	3.60	3.70	3.80	3.50	3.40
nasopharynx	3.60	3.70	3.60	3.70	3.70
pituitary gland	3.60	3.35	3.40	3.10	3.50
frontal lobe	2.50	2.85	2.50	2.30	2.70
temporal lobes	2.90	2.90	2.70	2.60	2.80
brainstem	2.30	2.40	2.20	2.10	2.40

Table 14. DWI mean scores of material at anatomic regions.

	Control	Ribbon	Gold	TMA	Stainless Steel
frontal lobe	2.80	2.90	3.00	2.90	2.80
temporal lobes	3.00	3.00	2.90	2.90	3.00
brainstem	2.90	2.85	3.10	2.90	3.20

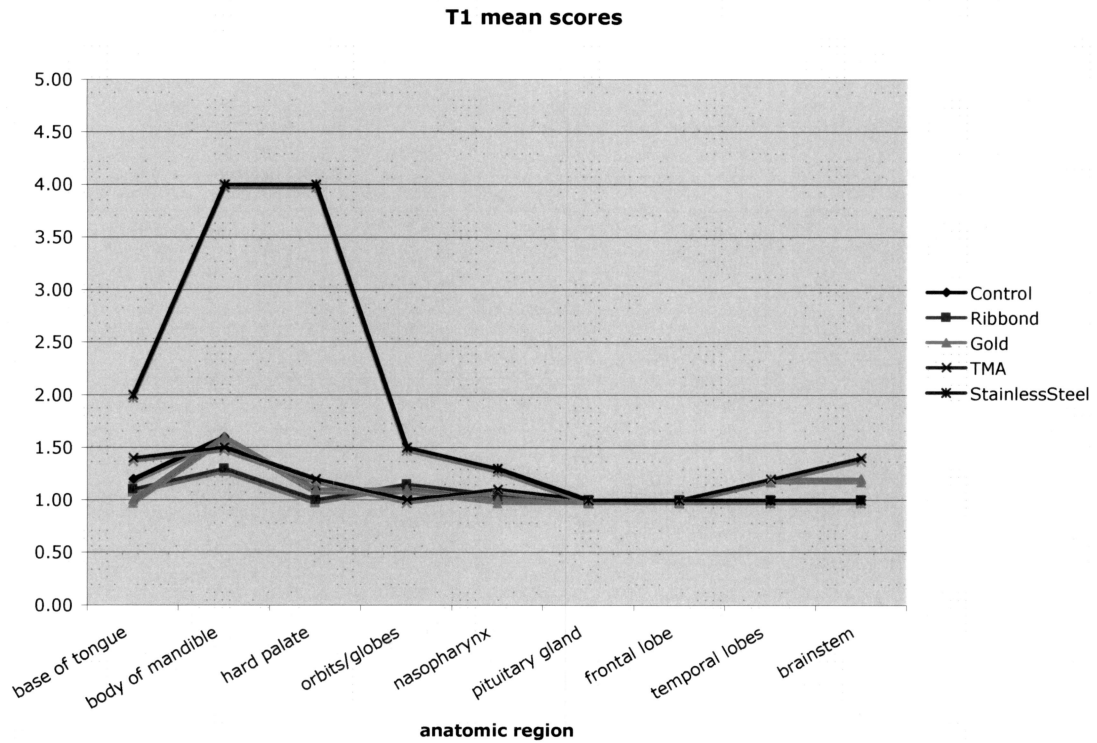


Figure 6. T1 Line graph of mean distortion scores.

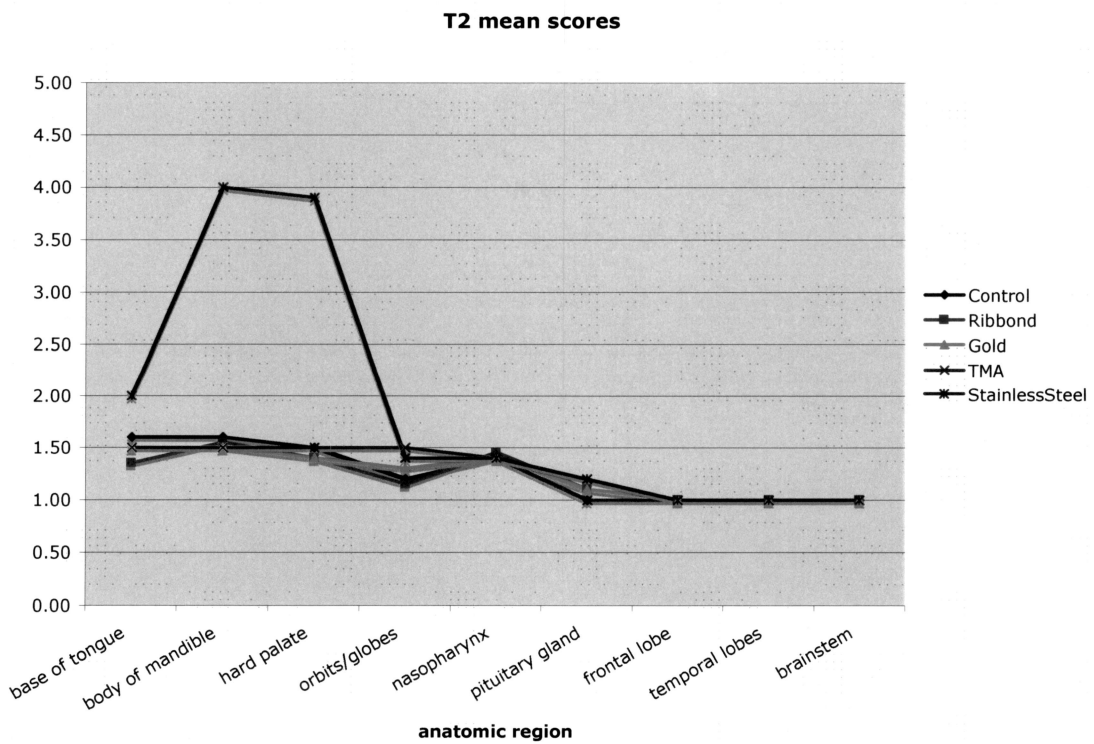


Figure 7. T2 Line graph of mean distortion scores.

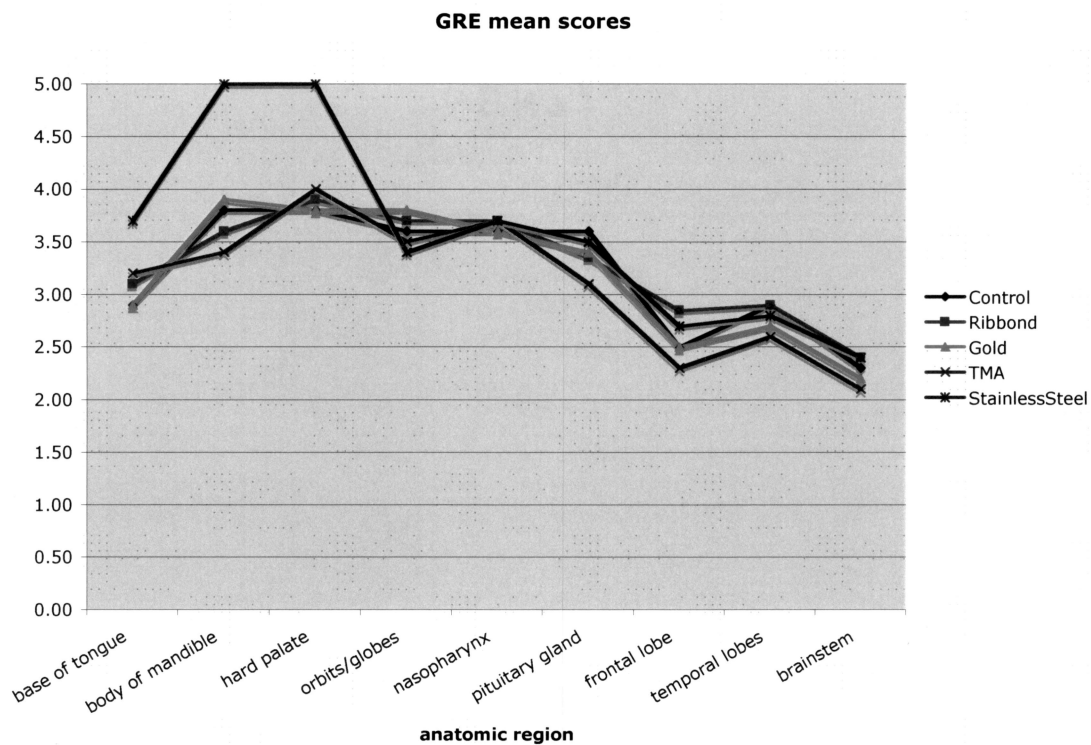


Figure 8. GRE line graph of mean distortion scores.

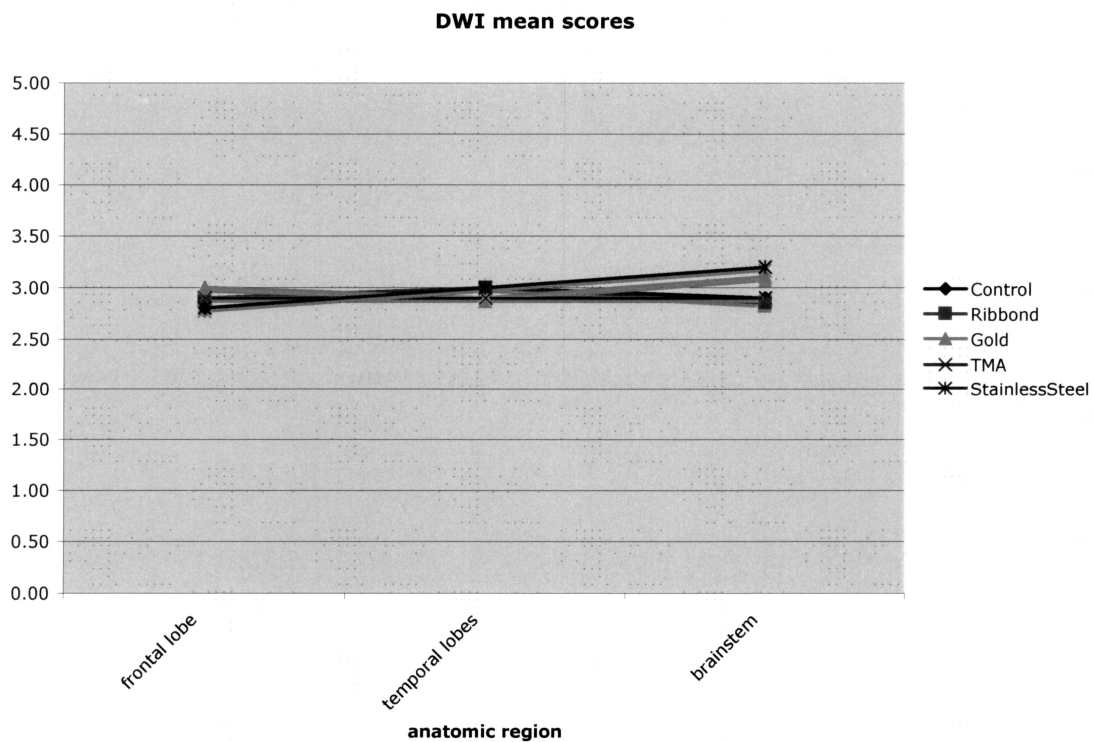


Figure 9. DWI line graph of mean distortion scores.

CHAPTER FOUR

DISCUSSION

Comparing lingual retainer material effects on image distortion gave statistically significant differences between stainless steel and all the other materials. Numerous studies have reported varying effects of image quality due to the type of dental material present. Lissac et al,²² found that precious alloys had no effect on MRI images while non-precious alloys produced large disturbances in the images. Dental materials such as aesthetic brackets without metal slots appear to cause minimal distortion of MR images.^{18,27} Egger et al,²⁵ reported that titanium, gold and amalgam caused no reduction in the image quality of MRI sequences taken of the oral and maxillofacial region for imaging for implant planning. Post surgical metallic residues and dental bur fragments are even suspected to create MR artifacts in the oral and maxillofacial region.^{28,29} This study confirms the results of other studies comparing dental materials with different magnetic properties.

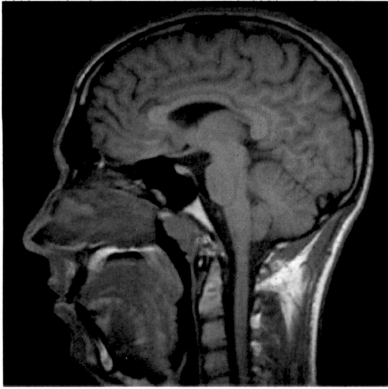
With no agreed upon length of time for orthodontic retention, it is not uncommon for orthodontic patients in retention to have their fixed lingual retainers in place for a decade or more.¹⁰ This is a period of time well beyond the two years that orthodontic patients are in braces during which time if routine MR imaging is needed of the maxillofacial region doctors request the removal braces. Retention patients often forget that they even have them and because they are not easily visible they could be missed

during the screening process for MR imaging. The presence of a fixed mandibular lingual retainer might not be discovered until the patient is being scanned requiring the patient to be rescanned. This is costly and time consuming.

In this study distortion caused by stainless steel was limited to the anatomical regions around the lingual retainer material with no statistically significant amount of distortion seen within the contents of cranium. Even with stainless steel lingual retainers present, the diagnostic interpretation of MR images of the cranial contents taken at 1.5 tesla does not appear to be affected. However, for scanning medical conditions in the mandibular region such as squamous cell carcinoma any distortion of images compromises their diagnostic value.^{24,26}

The imaging of this study was performed within a magnetic field of 1.5 tesla. Imaging is now routinely performed in machines with higher tesla strengths. It is possible that materials that disturb the magnetic field could create more severe distortion. Distortion may also occur in anatomic regions further away from where the material is located.

The point of this study was to rank the distortion/diagnostic quality of images in a clinically relevant situation. Stainless steel produced nondiagnostic mean distortion scores for the anatomic regions of the hard palate and body of mandible. Figure 10 illustrates the effect each material had on the T1 imaging modality. Stainless steel (Figure 10e) shows obvious distortion in the anterior region of the oral cavity. While the mean distortion scores for the base of the tongue in the T1 and T2 imaging modalities were diagnostic, all three raters commented that there was significant distortion seen in



a)



b)



c)



d)



e)

Figure 10. T1 sagittal images with appliance trays in place: a) Control, b) Ribbond, c) Gold, d) TMA, e) Stainless Steel.

the anterior portion of the tongue. Future studies evaluating image distortion may need to define more specific anatomic regions of interest.

Over half of the mean distortion scores for the GRE imaging modality were scored above 3.0 (nondiagnostic). However, only statistically significant differences in the material scores were found for the base of tongue, body of mandible, and hard palate. One possible explanation for this is that the GRE imaging modality is sensitive to anatomic regions where there is a bone-air space interface. An increase in mean distortion scores for the other anatomic regions due to materials is not statistically supported.

Movement of subjects during the MR scan can create distortion of images thereby affecting the images diagnostic ability.³⁰ All three raters commented on this during viewing of the images. Studies conducted without live subjects or using phantoms remove this limitation inherent in a clinical setting.^{21,25} However, in these studies the clinical relevance is reduced.

Statistically significant anomalies caused by the materials within the GRE imaging modality could possibly be due to the inherent susceptibility to distortion of the imaging modality itself.²³ The same can be said for diffusion weighted imaging (DWI) although there was no statistically significant difference in regards to this imaging modality. The anomalies could also be due to the fact that because of the large number of variables and repeated tests within the study there is a greater chance for a test result to be statistically significant. Although these anomalies occurred, they were not confirmed by the Friedman test.

CHAPTER FIVE

CONCLUSIONS

1. At 1.5T there is a statistically significant difference ($p < .05$) in distortion of T1, T2, and GRE magnetic resonance images caused by lingual retainer materials.
2. Stainless steel mandibular retainers caused significant ($p < .05$) distortion in MR images at the base of the tongue, body of the mandible and hard palate in the T1 T2, and GRE imaging modalities.
3. Mean distortion scores for stainless steel in the regions of the body of mandible and hard palate were above 3.0 in the T1, T2, and GRE imaging modalities. These distortion scores indicate that the images were nondiagnostic.
4. Ribbond (Polyethylene fiber), gold chain, and TMA did not affect the diagnostic quality of magnetic resonance images taken at 1.5T.
5. Stainless steel mandibular retainers have little effect on the interpretation of cranial MR scans taken for analysis of the contents of the cranium. However this study did not evaluate whether or not a neuroradiologist would accept an orally distorted scan for use in diagnosing cranial disorders.
6. Orthodontists should consider using mandibular retainers that do not affect the diagnostic quality of MR images for patients who undergo routine MR scans as part of their health care.

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APPENDIX A
INFORMED CONSENT

**INFLUENCE OF MANDIBULAR FIXED RETAINERS ON DIAGNOSTIC QUALITY
OF CRANIAL MRI**

PURPOSE AND PROCEDURE

The department of Orthodontics and Dentofacial Orthopedics at the Loma Linda University School of Dentistry is conducting a research study on the amount of distortion generated on Magnetic Resonance Imaging scans caused by common orthodontic appliances. You are invited to participate in this study because you are healthy, over 18 years of age, and free of major metal containing dental work such as full metal crowns, porcelain fused to metal crown, major amalgam fillings, implants, or fixed orthodontic retainers.

The purpose of this study is:

1. To evaluate the amount of artifact generated by various orthodontic permanent lingual retainers
2. To create recommendations when treating patients being monitored through the use of MRI
3. With the help of radiologists, determine what areas of the head and neck can be accurately read in patients with various orthodontic appliances

If you agree to participate in this study, the following activities will take place:

1. Since the MR scanner uses magnetic fields when scanning, you will be screened so as to determine your eligibility based on whether or not you have metal implanted or embedded in your body.
2. If you are eligible, two weeks before the scans will occur, a polyvinylsiloxane impression of the lower arch will be taken and five appliances will be generated in the lab.
3. Following the fabrication of the various appliances, each will be sequentially put in your mouth to ensure proper fit and comfort.
4. Five different scans, one per appliance, totaling approximately 1.5 hrs with short breaks between each scan to change appliances, will be performed. The study does not require special preparation or injections to perform.

Date: _____

Initial: _____

1 of 3

INFLUENCE OF MANDIBULAR FIXED RETAINERS ON DIAGNOSTIC QUALITY OF CRANIAL MRI

5. The data will be recorded and statistically analyzed to determine if and how much deformation of the MRI scans is caused by the various orthodontic appliances.

RISKS

The committee at Loma Linda University that reviews human studies (Institutional Review Board) has determined that participating in this study puts you at minimal risk of discomfort, harm, or injury.

The risk associated with MR scanning relates to whether or not you have metal in your body. You will be thoroughly screened to ensure that you have no metal implants or devices that would be MR incompatible and cause you harm. An additional risk of having an MR scan is if a person takes a metal object into the room while you are being scanned. This object may become a projectile and cause you harm; however, security procedures to prevent this are in place. No adverse incident has taken place at the Loma Linda institution in the 10 years of operating MR scanners.

BENEFITS

Although you will not benefit individually from participating in the study, we hope this project will help orthodontics and radiologists alike to be aware of the distortion generated by various orthodontic appliances. Patients who need MRI's for routine medical follow-up often require the removal of orthodontic appliance (fixed lingual retainers) prior to the scan, and then return to the orthodontist to have the lingual retainers put back on. This research will help determine what appliances are acceptable to wear when undergoing an MRI evaluation of the head and neck, eliminating as much patient discomfort as possible.

PARTICIPANT'S RIGHTS

Enrolling in the study is voluntary. Your decision whether or not to participate or stop at any time will not affect your relationship with Loma Linda University or the School of Dentistry.

CONFIDENTIALITY

Information about your MRI scans will be entered into the research record. Any data or published document resulting from this study will not disclose your identity without your permission.

COMPENSATION

Subjects will be compensated one hundred and twenty-five dollars (\$125) upon completion of all scans to allow full data collection. Subjects are free to discontinue the study at any time. Subjects will not be charged for the scans.

Date: _____
Initial: _____

INFLUENCE OF MANDIBULAR FIXED RETAINERS ON DIAGNOSTIC QUALITY OF CRANIAL MRI

IMPARTIAL THIRD PARTY CONTACT

If you wish to contact an impartial third party not associated with this study regarding any complaint you may have about the study, you may contact the Office of Patient Relations, Loma Linda University Medical Center, Loma Linda, CA, 92354, phone (909) 558-4647 for information and assistance.

INFORMED CONSENT STATEMENT

I have read the contents of the consent form and have listened to the verbal explanation given by the investigator. I have received a copy of the California Experimental Subject's Bill of Rights and have had these rights explained to me. My questions concerning this study have been answered to my satisfaction. I hereby give voluntary consent to participate in this study. Signing this consent does not waive my rights nor does it release the investigator(s), institution, or sponsors from their responsibilities. I may call Dr. Leggitt (909) 558-4604 or Dr. Carter (909) 558-4604, if I have additional concerns. I have been given a copy of this consent form.

Signature of subject

Date

Signature of witness

Date

I attest that the requirements for informed consent from the medical research project described in this form have been satisfied – that the participant has been provided with a copy of the California Experimental Subject's Bill of Rights, that I have discussed the research project with the participant and explained to him or her in nontechnical terms all of the information contained in this informed consent form, including any risks and adverse reactions that may reasonably be expected to occur. I further certify that I encouraged the participant to ask questions and that all questions asked were answered.

Date: _____

Time: _____ A.M./P.M.

Signature: _____

(Study Doctor)

Date: _____

Initial: _____

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APPENDIX B

DATA COLLECTION FORM

Appliance

Subject #: _____

Radiologist #: _____

Date of Scan: _____

	T1 Sag	T2 Axial	GRE	DWI
Base of Tongue				X
Body of Mandible				X
Hard Palate				X
Orbits/Globes				X
Nasopharynx				X
Pituitary Gland				X
Frontal Lobe				

Temporal Lobe

Brain Stem

N/I = not included

1-5 = 1 is best 5 is worst

APPENDIX C

DATA CODING KEY

Subject

1 = 1	6 = 6
2 = 2	7 = 7
3 = 3	8 = 8
4 = 4	9 = 9
5 = 5	10 = 10
Cohort = subjects 3,4,9	

Radiologist

- 1 = rater 1
- 2 = rater 2
- 3 = rater 3

Appliance

- 1 = Control
- 2 = Ribbond®
- 3 = Gold
- 4 = TMA
- 5 = Stainless Steel

Region

- 1 = base of tongue
- 2 = body of mandible
- 3 = hard palate
- 4 = orbits/globes
- 5 = nasopharynx
- 6 = pituitary gland
- 7 = frontal lobe
- 8 = temporal lobes
- 9 = brainstem

Imaging

- 1 = T1 sagittal
- 2 = T2 axial
- 3 = GRE
- 4 = DWI

APPENDIX D

RAW DATA

Rater 1

Subject	Radiologist	Appliance	Region	Imaging	Score	Cohort score
1	1	1	1	1	1	
1	1	1	1	2	1	
1	1	1	1	3	2	
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1	1	1	2	2	1	
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1	1	1	3	4		
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1	1	1	4	4		
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1	1	1	5	2	1	
1	1	1	5	3	2	
1	1	1	5	4		
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1	1	1	6	4		
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1	1	1	9	2	1	
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Rater 2

Subject	Radiologist	Appliance	Region	Imaging	Score	Cohort score
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Rater 3

Subject	Radiologist	Appliance	Region	Imaging	Score	Cohort score
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